

conductive heating area. A catalyst is deposited by electroless plating on the reformer side of the separator.

[0008] These prior art plate reactors to date have not been widely adopted by the art, and they appear to present the following types of concerns and problems: In US Pat. No. 5,015,444 of Koga et al., the combustion and reforming catalysts are in the form of powders or pellets filling the gaps between plates. The catalytic materials are not adhered to the partition walls; hence, the heat generated on the combustion catalyst must be transferred to a gas phase before reaching the reforming catalyst. As stated above, because a gaseous stream transfers the heat of reaction, the volume of the reactor is consequently large. In US Patent No. 5,167,865 of Igarashi et al., the reforming catalyst is deposited on the wall of the reforming channel. Thus, the heat of reaction is transferred from the channel wall to the catalyst in the reforming channel through the channel wall only, and a fluid-solid heat transfer step still must take place in the combustion channel.

[0009] Verykios, X. E. and Ionnides, T., in *Catalysis Today*, Vol. 46, No. 2-3, pp. 71-81 (1998) described another integrated heat transfer reactor. This reactor consisted of a hollow ceramic tube within a ceramic test-tube shaped well, with both the inside and outside surfaces of the hollow tube coated with similar or different metal catalyst films. The methane/oxygen feed enters into the hollow center core of the inlet tube, and reacts by contact with the first combustion catalyst film, then passes out the inner end of the tube, reversing direction and passing along the annulus between the inlet tube and the well where it contacts the reforming catalyst. A large fraction of the heat generated on the inlet tube inside wall by combustion was transported across the ceramic tube wall towards the outer catalyst film, where the endothermic reforming reactions occurred. In this reactor, the heat of combustion is transferred from the combustion catalyst to the reforming catalyst only through solid, relatively thick walls. This should result in a more compact design; however, this reactor is just a laboratory-scale unit that does not scale-up well.

[0010] Accordingly, there is a need in the art for an improved plate-type reformer with the inherent size advantages of the hollow ceramic tube reactor, but without the scale-up difficulties present in that design.

DISCLOSURE OF THE INVENTION

Summary, Including Objects and Advantages:

[0011] The present invention is directed to a modular, stackable unit, flow-through plate or channel reactor for continuous, low temperature, catalytic reactions of two separate process reaction streams; typically the first is an exothermic combustion process and the second, an endothermic reforming process. The reactor consists of two separate sets of flow channels or slot-type reaction zones located between spaced, thin metal, highly heat-conductive separator walls, and which includes a common, medially located, bicatalytic separator plate, i.e., a separator plate having on opposed surfaces the same or different catalysts selected for the particular reaction taking place in the adjacent reactor zone. The channels are configured and manifolded for simultaneous passage of the different process reaction streams, in co-current, countercurrent, or cross-flow modes. The combustion process reactant stream leads to a high temperature exothermic reaction in the presence of a selected catalyst coated on at least a portion of the first channel wall, preferably the medial wall surface facing the combustion zone. The reforming process reaction stream simultaneously undergoes an endothermic reaction, also in the presence of a catalyst coated on at least a portion of the second channel wall, again preferably on the medial separator plate surface facing the reaction zone.

[0012] This invention is particularly characterized as an apparatus and process for low temperature bicatalytic combustion/reforming with low NO_x formation, and more particularly with respect to the apparatus, to a reactor system employing

modular, stackable bicatalytic cell units having separate flow streams in intimate heat transfer relationship; these streams may be used in co-flow, counter-flow or cross-flow. No open flame combustion is involved. The reactant gases flow streams may be routed through any one or more of open volume flow, or continuous sinusoidal, parallel, or separate inter-digitated channels for precise flow control and heat transfer management without hot spots. A plurality of the bicatalytic modular reactor units or cells may be assembled and bolted together into a stack, the size of which is determined on the output requirements and/or portability. Alternately, the modular cell units may be bonded together to form a monolithic reformer stack.

[0013] The flow paths are configured in the reactor apparatus with the first set of flow channels adjacent to and in intimate heat exchange with the second set of flow channels through a common channel wall. It is preferred that the catalytic surfaces in each cell be in opposed relationship. That is, the catalyst surface in one channel-type reaction zone is directly on the opposite side of a common separator plate on the other side of which is disposed the catalytic surface of the other channel/reaction zone, such that the exothermic heat of reaction generated by the catalyst in the first set of flow channels is conductively transferred directly through the separator plate to the catalyst for the endothermic reaction in the second set of flow channels. In a preferred embodiment of this invention, the flow-through reactor is used to carry out simultaneous catalytic combustion of methane and catalytic methane reforming. The catalyst concentration/catalytically active surface area is balanced between the two sets of channels such that the heat generated by the exothermic reaction is entirely consumed by the endothermic reaction, thereby avoiding the presence of hot spots or heat imbalances on the catalytic surfaces that may deactivate or sinter if exposed to high temperatures.